BUILDING SAFETY INTO THE HIGHWAYS

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In recent years many articles have appeared in technical journals on, and much discussion has been given in engineering meetings to the various phases of highway location, design, construction, maintenance, finance, operation, and administration. Emphasis has also been placed on the large amount of money that has been expended by the various governmental units on road improvements and maintenance. The writer believes, however, that the safety element as applied to the highway problem has not received as much attention as it deserves. In this paper, therefore, I will endeavor to present the main features of design and construction which should be given consideration with respect to the elements of safety.

Safety, as applied to a highway, can not be defined in absolute terms but must be considered on a relative basis. Traveling in a motor car at forty miles an hour may be safe with a certain combination of alignment, gradient, weather, traffic, and driver, while ten miles might not be a safe speed under other conditions. Danger is not alone confined to speed, as a very slow speed of vehicle may introduce or be the cause of danger at certain times. This may be the case when traffic is particularly heavy. The average driver becomes impatient if forced to follow a slow moving vehicle and in an endeavor to pass it will take chances of colliding with other vehicles. The factors that influence safety problems are so varied and numerous that no complete solution is possible. The various points to be considered, however, are generally applicable to all highways.

The remainder of this discussion will be confined largely to the conditions encountered in the work of the Pennsylvania Department of Highways. At the present time all phases of the problems involved in safe location, construction, and maintenance are given careful study and consideration prior to the preparation of construction plans.

Location

A road should be relatively straight when the topography permits construction at reasonable cost. Curves and grades should be as light as practical. From an analysis of 1,277 traffic accidents which occurred in 1926 and which were scattered throughout the state, the following comparison was made: Assuming the number of accidents on a straight,

comparatively level road to be one hundred per cent, there was the same percentage on straight road with light grades, 105 per cent on light curves, 508 per cent on steep grades, and 875 per cent on sharp curves. Light curves were assumed to be less than ten degrees and light grades less than six per cent. This analysis indicates clearly the extra hazard on sharp curves and steep grades. It is the policy, where practicable, to hold the curves to a maximum of 5° 44′, radius 1,000 feet, and the grades to a maximum of six per cent. On some mountain routes eight per cent grades are used, with lighter grades interposed at intervals of 2,000 feet or less. From traffic studies which the department made, the desirability of breaking maximum grades at intervals with lighter grades in order to enable the driver to retain proper control of the car on descending and to prevent undue slow speed in ascending was clearly demonstrated.

The combination of line and grade is given particular attention. Sharp curves at the bottom of long or heavy grades or at the end of long tangents are very undesirable. These combinations can be avoided many times by more careful study of the location, but when relocation is impracticable because of difficult topography and excessive cost, a special design should be devised to reduce the danger. An example of such a problem and the solution is found on Pennsylvania Legislative Route No. 29 in the Seven Mountains of Mifflin County. (Fig. No. 1.) For many years there was a hairpin turn on a very steep grade which was the scene of many accidents. When this route was improved in 1926 with a hard surface pavement, the hairpin turn was expanded to a 25-degree curve,

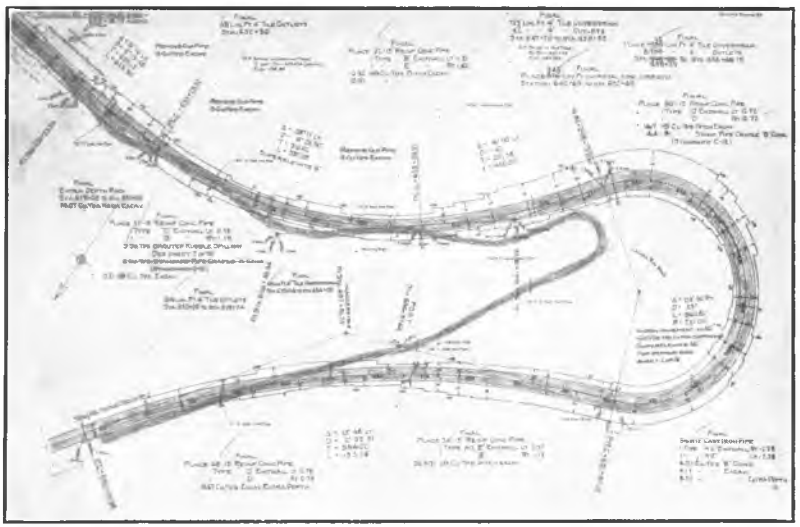

Fig. 1. Route No. 29. Seven Mountains, Mifflin County.

the pavement was widened to thirty feet, with a curb on the outside and standard shoulder on inside, and superelevated one inch per foot of width. As a result of this design, no accidents have been reported at this point since the construction was completed.

Reverse curves with little or no tangent between them are dangerous. We require a minimum tangent of 150 feet between curves in opposite directions but endeavor to adjust the alignment to secure a greater distance.

Sight Distance

A minimum sight distance of 400 feet, assuming the line of sight to be five feet above the road surface, has been required on all vertical and horizontal curves and at under and over crossings of railroads. However, with the present tendency of highway speeds of vehicles, this is not sufficient and the standard must be increased. I recommend 500 feet as a minimum wherever possible.

Superelevation

To promote the comfort and pleasure of the motorist and to increase safety by eliminating or reducing the tendency of the vehicle to skid, curves should be superelevated. The minimum curve to be superelevated and the rate of superelevation are debatable points. At present the policy in Pennsylvania is to superelevate curves sharper than 2° 52′, radius 2,000 feet, one-half to three-quarters of an inch per foot width of pavement. In exceptional cases only is one inch per foot superelevation used. Theoretical values of one inch or greater are justified on sharp curves for high speed vehicles but a slowly moving car or truck may skid or slip toward the inside of the curve when the pavement is coated with sleet or snow. The tendency in recent years has been to superelevate curves of smaller degree, particularly where the curves are long, than was formerly deemed necessary. I believe the policy will be extended in the comparatively near future to curves of 2 degrees and possibly to those of 1 degree.

Widening of Curves

As the degree of curve increases, danger is created by the "overhang" of vehicles. Therefore, to provide safe clearance the pavement should be widened. Our practice is to widen pavement on curves of 9° 32′, radius 600 feet or over, from two to six feet. I believe this widening should begin with curves of 8 degrees, radius 716+ feet.

Crown

A high crown is not only undesirable and unnecessary on any road with modern methods of construction and mainte-

nance, but it may also become a positive danger. On hard surface roads the crown should be sufficient only for proper drainage. Our standard is one inch for surfaces eighteen and twenty feet in width. Additional widths on the sides are sloped not to exceed one-quarter inch per foot. On widened curves the crown is removed and a straight surface is used.

Pavement Surface

The surface of the pavement should be finished true and free from humps and hollows. It is common practice to allow a vertical tolerance of one-quarter inch in a longitudinal distance of ten feet. This variation can be, and often is, greatly reduced by proper attention to the details of finishing.

The surface of new pavements is checked by a car equipped with a mechanical device to indicate the roughness. This permits a comparison to be made of the surfaces on different pavements and promotes uniformity of results throughout the state.

In the case of a concrete pavement a natural belted or wood float finish is required, which leaves a slightly granular surface rather than the old style smooth sidewalk finish. On very steep grades, concrete with a broomed surface, hillside or brick with wire cut surface up, or a special open surface bituminous pavement may be used to give better traction and to reduce the danger of slipping or skidding.

Under particularly adverse weather conditions when snow and sleet occur, any type surface may become slippery and dangerous for traffic. This is a maintenance matter and is remedied by spreading cinders or sand on the pavement.

In order to increase the convenience and safety of driving in the winter our snow removal program includes about 8,800 miles of roads. Temporary snow fences are erected where much drifting would occur. Maintenance forces are organized and mobile equipment is ready at all times to remove snow from the road surface as soon as a snow storm begins. On first removal the snow is plowed out approximately three feet from edge of pavement. This provides room for snow on subsequent removal without encroaching on edge of pavement. It also keeps the road surface free from melting snow. The cost of our snow removal for a normal winter is approximately $100 a mile or about fifty cents per vehicle licensed in the state. Prevention is better than later remedies, and the cost, we believe, is more than justified by the results.

Shoulders

The shoulders or berms should be well constructed and maintained level with the edge of the pavement. The slope away from the pavement should not be so great as to cause a vehicle to overturn if it runs off the pavement nor should

it prevent the vehicle from easily returning to the pavement. The Pennsylvania standard shoulder has a drop of 1½ inches for each foot of width. This slope is carried to the ditch line or to the edge of excavation or embankment slope. When necessary on steep grades to carry surface drainage in excavations adjacent to the shoulder for several hundred feet, our present policy is to construct a paved shoulder with an integral curb on the outside. This eliminates the danger of a soft shoulder and virtually provides an extra lane for travel. The ideal shoulder should be composed of a material that has sufficient stability to resist normal erosion and strength to support the wheel loads that may come on it. I believe that in general shoulder construction and maintenance have not been given the attention by highway officials that they deserve. Many accidents are caused by wheels of vehicles sinking into a soft shoulder or by the wheels skidding on the edge of a hard surface pavement where the shoulder is not maintained level with the pavement.

Where there is a large amount of traffic on a road the capitalized cost of an extra foot of width of pavement on each side should be compared with the cost of shoulder maintenance. Often it will be found that the increased safety to travel and decreased cost of maintenance fully justify the wider pavement.

Pavement Widths

To provide safe clearance between passing vehicles, pavement should be not less than twenty feet in width on main highways, thus providing ten-foot lanes. Eighteen feet should be the minimum on secondary roads where there is very little truck traffic. The safe width is influenced not only by the size and number of vehicles but also by the speed. As traffic increases beyond the capacity of two-lane pavements, one or more additional lanes should be provided. In Pennsylvania both thirty and forty foot pavements have been built on some of the main highways in recent years. Contrary to the opinion expressed by some engineers, we have not found three-lane roads to be more dangerous than four-lane roads but full traffic benefit will not be realized and danger may result unless the traffic lanes are defined by proper marking on the pavement or by longitudinal joints.

Longitudinal Joints

Concrete pavements are usually constructed with a longitudinal center joint. Where the surface is more than two-lane width a longitudinal joint is formed between each lane. This joint acts as a safety factor in preventing irregular longitudinal cracking of the pavement, and also, when filled with bitumen, serves as a stripe or guide to traffic. If there is no longitudinal joint in the pavement, the traffic lanes may be

defined by painted stripes. Experiments have been made by inserting metal discs, bricks, or colored blocks in the surface, but the results have not been entirely successful.

Guard Fences

On both sides of high embankments or on the outside of curves on embankments where a vehicle would probably overturn if it should suddenly swerve from the road, guard fences are erected. Wooden guard fences are dangerous and are obsolete on modern highways. Our standard fence has wood posts spaced ten feet apart, which carry two $\frac{3}{4}$-inch steel cables supported on cast iron brackets three inches from the face of the posts. (Fig. No. 2.) At particularly dangerous points the upper cable is one inch in diameter. This type fence, as

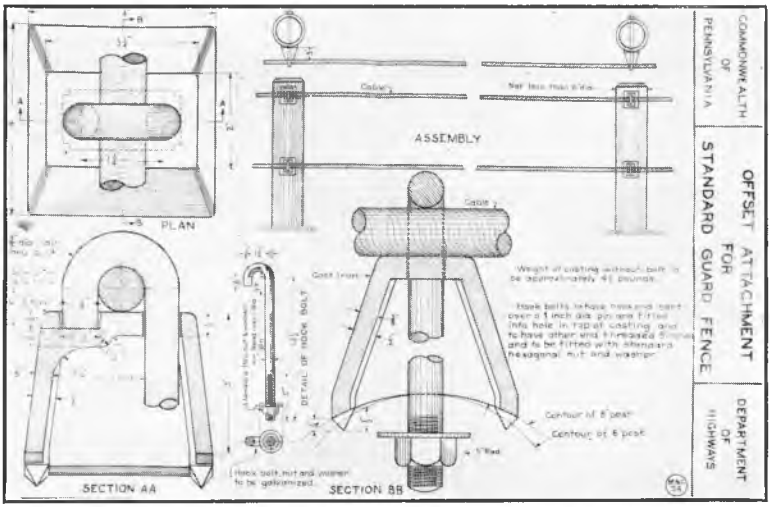

Fig. 2. Offset attachment for standard guard fence.

a result of extensive tests, is believed to provide maximum safety for both the vehicle and the traveler.

Bridges

Bridges are designed for a truck weighing twenty tons. The legal limit is thirteen tons. Therefore, ample provision is allowed for impact or possible increase of the legal limit in the future. Small bridges, without sidewalks, have a minimum 24-foot clear width for two lanes of travel. On primary routes the minimum width is 30 feet. It is probable that these widths will be increased in connection with a revision of standards in the near future. Where a bridge is near a borough, village, church, school, or closely built-up settlement, a five-foot sidewalk in addition to the widths just noted is

provided at the expense of the commonwealth. If a bridge or viaduct is situated adjacent to a curve or is on a curve, high parapets or through plate girder construction that would limit safe sight distance are not permitted in the design.

In order to prevent the settlement which may occur adjacent to the abutments of bridges from causing an unpleasant or dangerous sag in the pavement, the approach slabs are reinforced by bar mats. If a large shrinkage of the embankment is expected, a temporary type surface is placed until the embankment becomes stable.

Culverts

It is the present policy to extend pipes or small culverts, where the cost is not greatly increased, to provide ten-foot shoulders for future traffic lanes. Headwalls can be omitted usually on oulet end of pipe by lengthening the pipe one or two joints. The longer pipe culverts prevent the danger of a bottleneck at these points and make provision at small additional expense for future widening of the highway.

Elimination of Railroad Grade Crossings

Grade crossings of steam and electric railroads constitute one of the greatest dangers to highway traffic. Any factor that impedes the free movement of a motor car over such crossing creates an additional hazard. It is essential, therefore, that the alignment and grades adjacent to the crossing should be light and free from obstructions. Curves should not exceed six degrees, and grades should be less than six per cent. The crossing proper should be paved or planked smoothly or uniformly for a width preferably several feet wider than the paved highway. Where the traffic is heavy on both railroad and highway, grade separation is given consideration. Where the approach to a grade separation is dangerous, a "continuous flashing slow signal" is placed so as to be visible to approaching traffic for at least 400 feet. In Pennsylvania the average cost of the separation of grades is perhaps in excess of $60,000. This precludes the possibility of a complete separation of grades unless the operations are extended over a long term of years. It is doubtful also if the separation of all grade crossings could be justified. Efforts must be directed, therefore, to the elimination of the more dangerous situations and to better and more effective warning signs for the crossings that remain.

In this connection it may be of interest to know that the Pennsylvania Department of Highways, the Public Service Commission, and such railroad companies as may become parties thereto have agreed upon the establishment of a uniform type of warning signal. This is an "automatic red flashing track circuited signal." It is installed and maintained by the

railroad company. (Fig No. 3.) The Department of Highways pays one-half of the cost of installation. When a full view of these signals is less than 500 feet, an additional "advance warning continuous flashing yellow signal" is placed along the highway within 300 feet of the railroad grade crossing so as to be visible to approaching traffic for at least 500 feet. This is installed and maintained by the Department of Highways, the railroad company paying half the cost of installation.

Fig. 3. Automatic Red flashing track circuited signal.

Eliminating a crossing or avoiding it for through traffic can be effected sometimes by relocating the highway, the railway, or both.

In the separation of grades, the choice of an underpass or an overhead crossing depends largely upon the topography in the locality. Our underpasses are designed for a minimum vertical clearance of 14 feet, which requires 18 to 20 feet

from finished grade to base of rail. The minimum width is 24 feet. All underpasses provide for at least a narrow sidewalk outside of the paved roadway.

A crossing over a railroad requires a gross vertical distance of 26 feet or more in order to provide the necessary net clearance of 22 feet from top of rail to underside of structure.

Elimination of Highway Grade Crossings

The elimination of grade crossings on important highways is receiving attention of highway officials. Except where the volume of traffic is very great, usually in or adjacent to large cities, it has not been considered economically justified. The most notable examples at present are the Lake Shore Drive at Chicago and the New Jersey approach to the Holland Tunnel under the Hudson River. No doubt this problem will be given increasing study within the next few years.

Pedestrian Subways

Where there is a great volume of pedestrian traffic crossing a street, as in the vicinity of large schools, it may be desirable to decrease the danger to pedestrians and the slowing up of traffic by providing pedestrian subways. These have been confined to city or suburban locations of heavy population. Under the existing laws, our department is prohibited from participating in the cost of such structures.

Road Intersections

Often the danger at road intersections can be greatly lessened by changing the grade on one or both roads, by relocating the intersection, or by widening or daylighting the intersection. We have secured very favorable results in some cases by the widening of the intersection and rounding off the corners in one or more quadrants in order to better accommodate turning traffic. The curb radius of intersections should never be less than the minimum turning radius of a large passenger car or truck.

In Pennsylvania there is a special law relative to "authorizing the purchase or condemnation of unobstructed view at intersections of highways, railroads and railways and at curves." By authority of this law it is possible to eliminate existing obstructions to sight and to prevent the erection of any new obstruction.

Conclusions

It is entirely beyond the possibilities of the time available at this meeting to go into all phases of highway safety. Therefore, this paper has been confined largely to the more common problems arising in the processes of design and construction. I believe that the possibilities of providing reasonable

safety for the traveler on the road have been made clear. However, as previously indicated, safety is a relative condition, and road design which is safe today may need modification in a few years. The engineer or highway official who designs or plans his work on the basis of bare immediate necessities and cost and does not plan for reasonable future safety and development of traffic can not hope to remain long in his position.

In conclusion, I wish to emphasize the importance of the following items:

1. The dependence of safety upon several factors, including the driver, car, speed, weather, and design of highway.
2. Location of road, i. e., relation of alignment and grade.
3. Adequate sight distance.
4. Proper superelevation of curves.
5. Extra width on sharp curves.
6. Minimum crown of road surface.
7. A road surface free from inequalities and not slippery.
8. Shoulders properly constructed for safety of stable materials.
9. Adequate width of pavements for modern high speed vehicles.
10. Traffic lanes properly marked or defined.
11. Safe guard fences.
12. Wide bridges with safe approaches.
13. Pipe culverts of adequate length to give full roadway width between headwalls.
14. Elimination of railroad grade crossings where practicable.
15. Proper warning signs where railroad grade crossings are not removed.
16. A study of the possibility of eliminating highway grade crossings in exceptional cases.
17. Practicability of pedestrian subways.
18. Safe road intersections.

WHAT WHITLEY COUNTY HAS DONE TO ELIMINATE THE RIGHT ANGLE TURN IN ROADS

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Three years ago the highway department of Whitley County started, as a part of their campaign for increased safety and convenience of motor traffic, a movement that we have decided is one of the greatest safety measures we have as yet under-